Development and Evaluation of Innovative Arsenic Adsorption Technologies for Drinking Water by the Arsenic Water Technology Partnership

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Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Background

- Recent reduction of drinking water Maximum Concentration Level (MCL) for arsenic from 50 ppb to 10 ppb was intended to reduce incidence of bladder cancer and other cancers in US.
- Southwestern United States is characterized by high and variable background levels for arsenic
- Estimated national annual costs of implementing 10 ppb MCL range from $165M to $605M to save 7 – 33 lives.
  - $5M – $23.9M /life saved
  - $1.3M – $6.6M/ year of life saved
    - About 1 life/500,000 exposed persons per year
- New MCL is controversial due to high costs and uncertain health benefits.

Concerns About the Cost of the New Arsenic Standard

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Arsenic Water Technology Partnership Background

- Congressional Appropriation - $13M FY03 – FY06
- DOE- funded peer-reviewed, cost-shared research program to develop and demonstrate innovative technologies for removal and disposal of arsenic from drinking water
- Partner Roles
  - Bench-Scale Studies (AwwaRF)
  - Demonstration Studies (Sandia)
  - Economic Analysis/Outreach (WERC)
- Focus on small systems
  - 40% of resources directed to rural and Native American utility needs
  - Minimize costs - capital, operating, maintenance
  - Minimize residual quantities & disposal costs

Can advances in water treatment technology significantly reduce costs?

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Outline of Talk

- Processes important for performance of adsorptive media
  - What things can be improved
- Arsenic Water Technology Partnership Evaluation Programs
  - Sandia Vendors Forum
  - AwwaRF Grants
  - WERC Design Contest
- Moving innovative technologies to the real world

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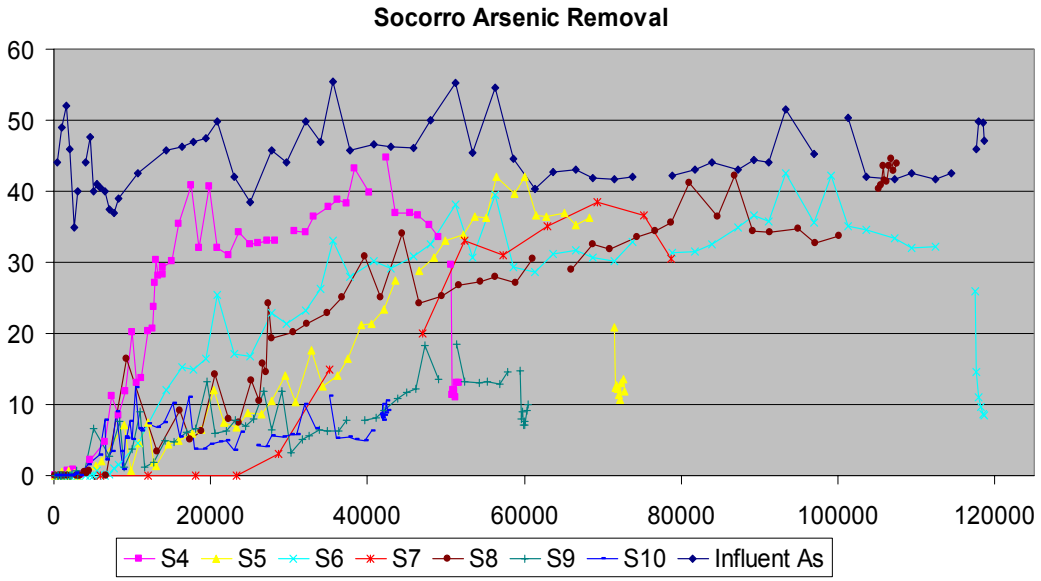
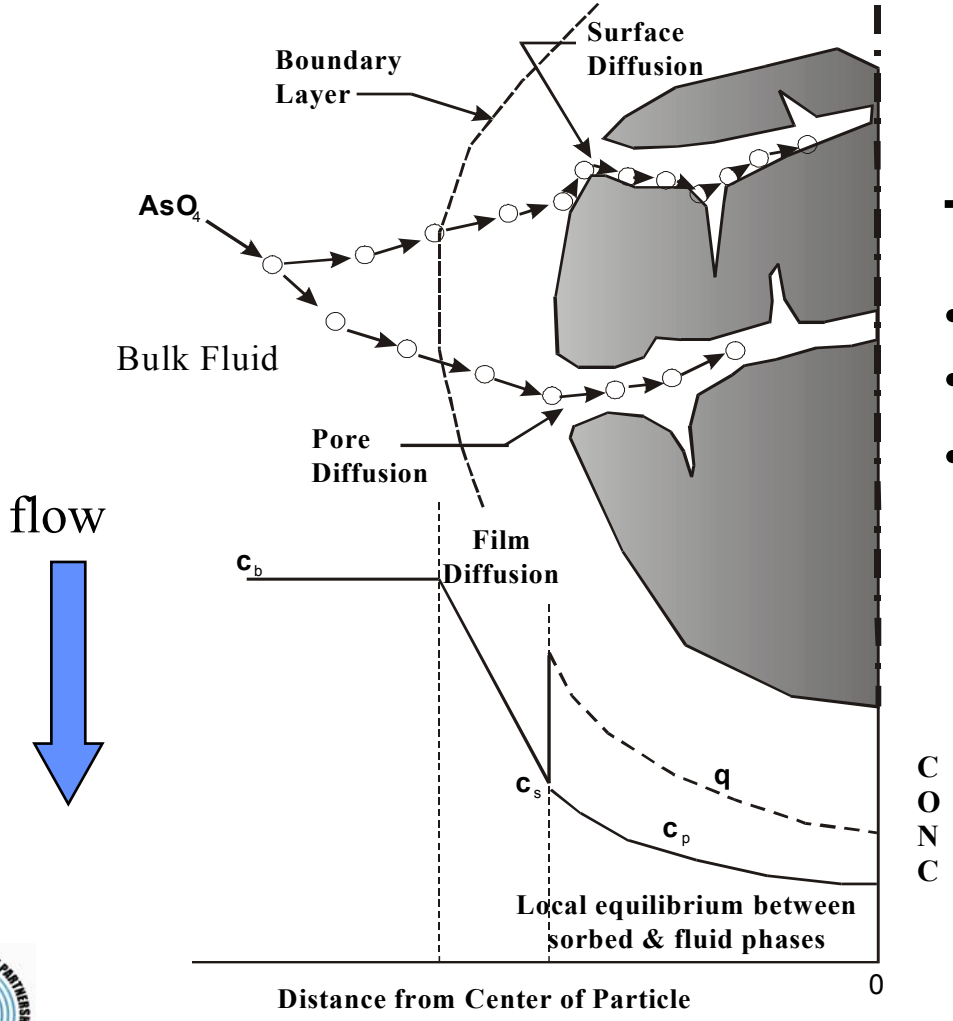
Packed Beds of Adsorptive Media

As



Performance of Adsorptive Media



Targets for Improvement

- Maintain flow
- Intraparticle diffusion rates
- Sorption equilibria
  - Controlled by redox, pH and ZPC

(after Aragon, 2004)

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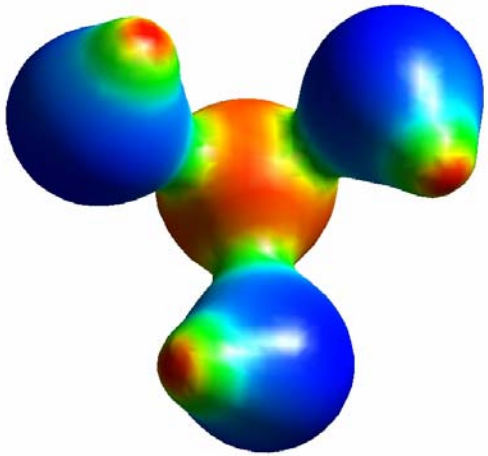
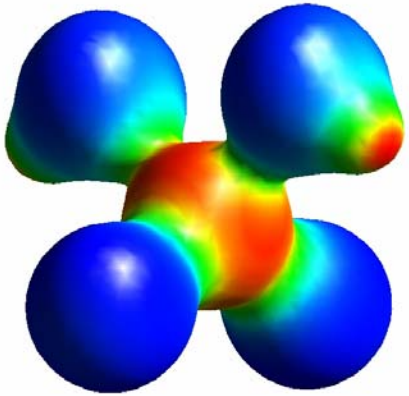
Arsenic Redox Speciation



H_3AsO_3



$H_2AsO_4^-$

Inorganic arsenic in groundwater usually exists as a combination of neutral As^{III} (arsenite) and anionic As^{V} (arsenate).

Arsenite is believed to be more toxic than arsenate.

Traditional treatment relying on adsorption removes arsenate more efficiently than arsenite because of coulombic attraction/repulsion.

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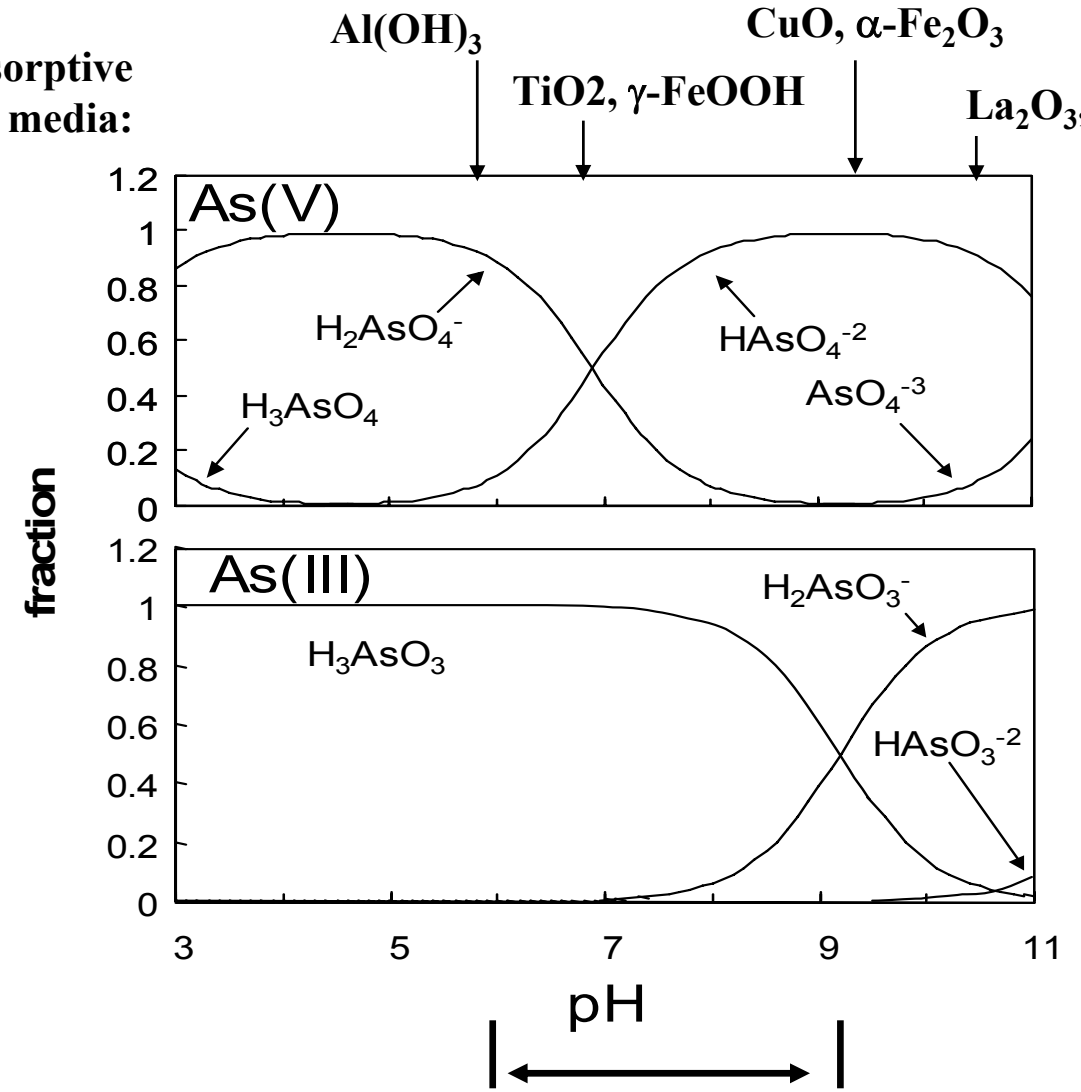
pH and Speciation

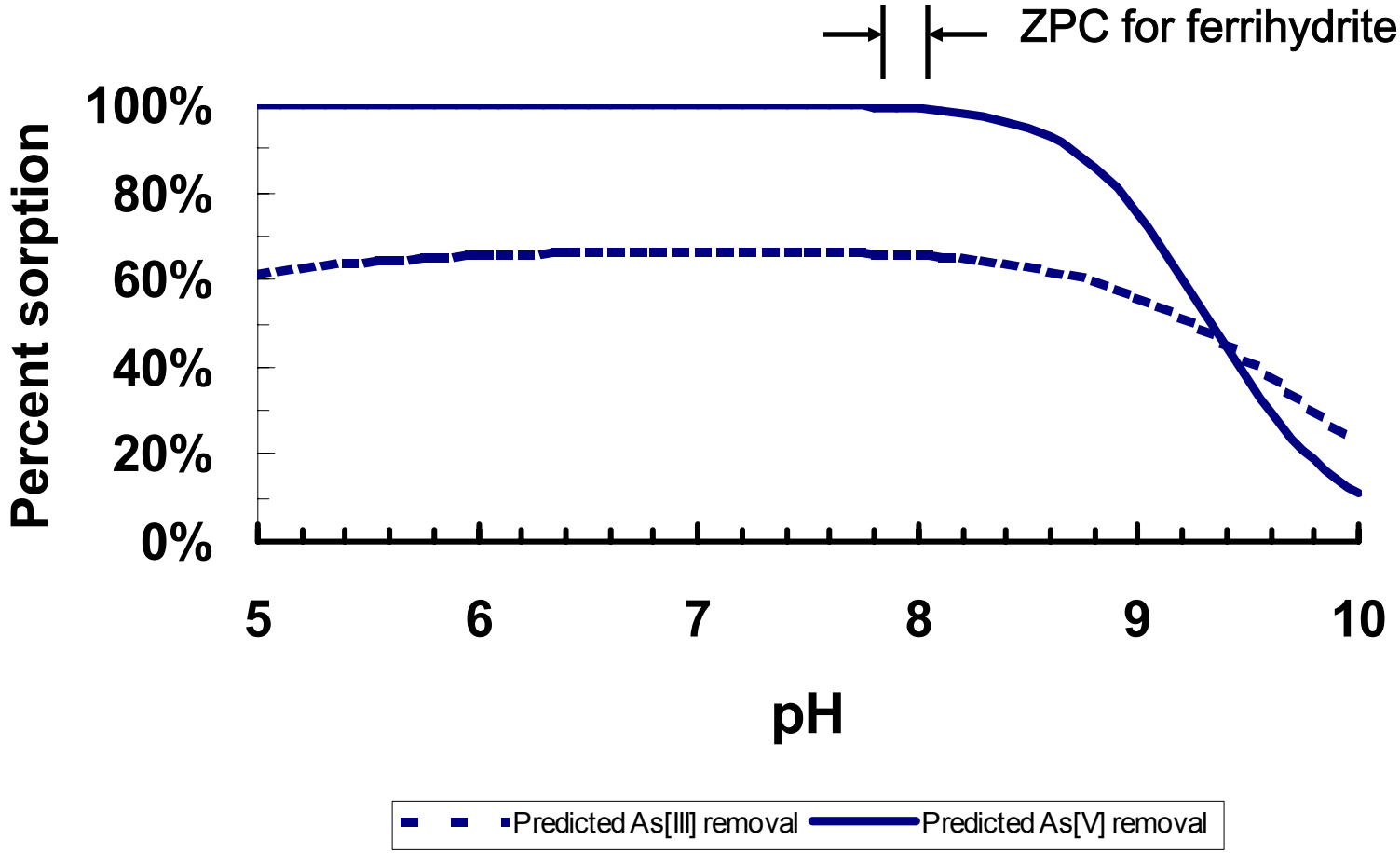
ZPCs of adsorptive media:

+ charge below pH ZPC

- charge below pH ZPC



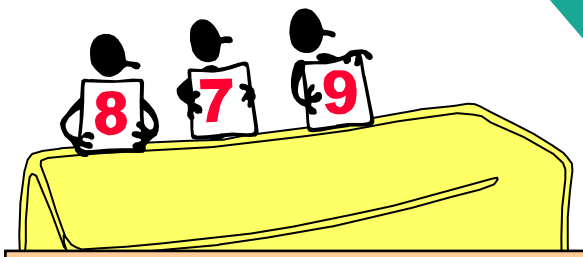
pH and Sorption by $Fe(OH)_3$



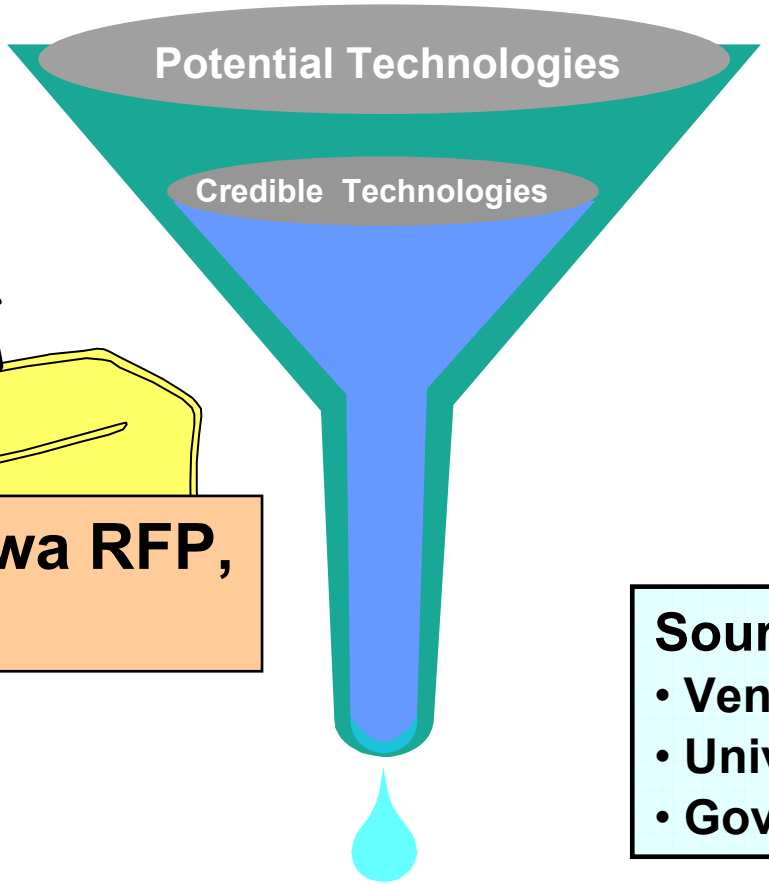
AWTP Technology Evaluation Programs

- **Sandia Arsenic Treatment Vendors Forum**
  - Open session allows Vendors to present product descriptions
  - Closed session review by Technical Evaluation Teams
- **Awwa Research Foundation**
  - Technical Review Committee defines research objectives
  - Grants are awarded through competitive, peer-reviewed RFP process
- **WERC Design Contest**
  - WERC utilizes its existing Design Contest in order to obtain innovative arsenic removal technologies.

AWTP Technology Evaluation Process



Forum, Awwa RFP, WERC



- Innovation
- Performance
- Cost
- Complexity
- Maturity

Sources of new technologies
- **Vendors**
- **Universities**
- **Government labs**

Suggested Pilot Technologies

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Sandia Vendor Forum Description

- **Held at *New Mexico Environmental Health Conferences* in Albuquerque, 2003-2005.**

- **Format**
  - **Public presentations by vendors.**
  - **Vendors privately interviewed by *Technology Evaluation Teams***
    - **Four five-person teams of water treatment experts at each Forum.**
    - **Each vendor interviewed by at least two teams.**

- **Twenty-seven different vendors evaluated at the three Forums.**
  - **Nine vendors in 2003, twelve in 2004, ten in 2005.**
  - **Four of the 27 vendors attended two Forums.**
  - **Two universities were among the 27 vendors.**

Vendors Forum Evaluation

- Each vendor was scored based upon six criteria:
  - Performance
  - Maturity
  - Cost
  - Implementability
  - Effect [on communities]
  - Innovation
- Highest scores generally given for Performance and lowest for Maturity, but numerous exceptions
- Overall Total score given to each vendor based upon a *weighted* value of each criterion.
- Most" of the vendors deemed viable candidates for Pilot testing.

General Treatment Innovations

- **Sorption treatment processes**
  - Regenerable, higher capacity and selectivity
  - More stable residuals
  - 'Tougher' sorbents
  - Coatings on inexpensive materials (industrial waste, natural materials)
- **Precipitation/filtration processes**
  - Enhanced coagulation with Fe compounds or polyelectrolytes
  - Improved filtration with nanocomposite materials
  - Recycle systems to minimize chemical addition

2003, 2004, 2005 Vendor Forums led to recommendation of innovative technologies for initial pilots and others for additional bench-scale studies

Top Five Ranked Vendors at Forums

2003	2004	2005
Hydroglobe – TIO_2	Purolite – Hybrid resin	Purolite
MEI - ZrO_2	Engelhard - GFO	ResinTech
Kinetico	*Filtronics*	EaglePicher – La-coated DE
AdEdge - GFO	DOW – TiO_2	ADA – Coated silicate
Filtronics	ResinTech – Hybrid resin	Virotec – mixed oxides from Bauxite

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Objectives of AwwaRF Bench-scale Studies

- **Reduce cost of treatment (O&M)**
- **Robust and easy to operate**
- **Low-cost, easy disposal of residuals**
- **Low energy consumption**
- **Investigative Approach**
  - new/innovative technologies
  - modifications to existing treatment
  - other (monitoring or management technologies)
- **Research Considerations**
  - Water quality impacts all technologies
  - Research leads to field testing of multiple technologies

Sorptive Media Projects Funded in 2004

- **Developing a New Class of Ion Exchangers for Selective Removal of Arsenic** (Cu-polymeric ligand exchanger)
- **Agglomerated Nanoparticle Media** (TiO_2/polymeric binders)
- **Aerogel & Iron-Oxide Impregnated GAC** (composite materials from hydrophobic sol-gel precursors + Fe-Mn-GAC chemical agents)
- **High Efficiency & Cost-Effective Zirconium & Titanium-Based Nanocomposites for Removal of Arsenic from Drinking water** (doping Ti and Zr oxide sorbents to improve performnace).
- **As Removal onto Activated Carbon Preloaded w/ Surfactant-Iron Complexes** (series system: As-Fe-complexes sorb onto tailored Fe- organic-GAC bed)

New Sorptive Media Projects Funded in 2005

- $FeCO_3(s)$ as an inexhaustible source of $Fe(OH)_3(s)$ for As removal (granular siderite packed bed)
- Evaluation of innovative regenerable & non regenerable adsorption media for As removal (Field-scale comparison of 2 regenerable media (AsX^{np} and Absorbtia –GTO)
- Low-cost As removal w/ treated coal ash (Use bottom ash as substrate for Fe-oxide coating in batch systems)
- Metal-doped hydro-gel media for As removal & brine minimization (Biopolymer with Fe immobilized throughout structure by coordination with carboxylate functional groups; can be dehydrated for low volume disposal)
- Removal of As by sorption to iron-coated fibers

AwwaRF Phase II Sorptive Media Projects: 2006 starts

- Fe and Ti- impregnated Granular Activated Carbon
  - Team: ASU, Clemson, SolmetTex
  - Optimize Fe oxide–GAC formulation for iron coverage and arsenic removal
  - Investigate TiO_2 -impregnated GAC
  - Investigate multiple contaminant removal
    - Arsenic, uranium, SOC
- GAC Modified with Organic Carboxyl-metal Complexes
  - Pennsylvania State University
  - Develop series treatment systems for small utilities
    - Zero-valent iron source for FeOOH sorbent
    - Removal of As-Fe complex by modified GAC bed
- Polymeric Ligand Exchanger for Highly Selective and Regenerative Arsenic Removal
  - Auburn State University
  - Test DOW 3N-Cu resin in field pilot
  - optimize operating parameters (EBCT, column config.)
  - Optimize regeneration with brine

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WERC Design Contest

- National competition for students and faculty
- Components that the student teams undertake:
  - Research and testing related to the task;
  - Publishable paper that describes the research, options considered, test results, full-scale cost projections, environmental and public considerations, and health and safety issues;
  - Professional level oral presentation;
  - Conference level poster presentation;
  - Demonstration of operational bench-scale solution to the task.
- AWTP funds further verification of selected technologies

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2003 and 2004 WERC Design Contests

2003: Arsenic Treatment for Small Water Delivery and Domestic Water Systems

2004: Arsenic Treatment for Domestic Water Systems

- **Teams developed and demonstrated a cost-effective treatment technology to remove arsenic from drinking water in small water delivery systems and domestic water systems.**
  - **2003**: **11 teams**: Clarkson, Clemson, Lafayette College, Mich. Tech., Montana Tech, Ohio University, SD School of Technology, Thadomal Shahani (India), Univ. ID, Univ. New Hampshire, Univ. Waterloo**.**
  - **2004: 6 teams:** Dalhousie University (Canada), LSU, Montana Tech., Ohio State University, Tufts Univ., and Widener Univ.

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2005 and 2006 WERC Design Contests

2005 - Arsenic Treatment for Rural Isolated Communities

- **Develop and demonstrate a cost-effective, energy-efficient treatment technology to remove arsenic and nitrate from drinking water in the presence of other competing ions such as silica and phosphate in rural isolated communities.**
  - 11 teams: Clemson, Duke, Lafayette College, Montana Tech., NMSU, Stevens Inst. Of Tech., Univ. Manitoba, Univ. NM, Univ. Waterloo, Univ. Wyoming, Washing Univ. at St. Louis.

2006 - Arsenic Treatment for Rural Isolated Communities

- **remove arsenic from (high TDS = 1000) ppm) challenge water**

Summary of Current Sorption Treatment Innovations

- Fe, Ti, Cu, Zr or mixed metal oxides in granules formed by chemical precipitation or nanoparticle agglomeration. (e.g. AdEdge, Kemiron, Argonide, Graver)
- Coating granular activated carbon (GAC), strong base anion exchangers resin or polymeric ligand exchangers with nanoparticulate metal oxides. (e.g. Purolite, Resintech, Auburn University, Arizona State)
- Coating inexpensive natural media or waste products with metal oxides or other functional groups. (e.g. ADA, Virotec, Lawrence Berkeley Labs)
- Increased surface area and chemical selectivity based on fibrous or gel substrates coated by metal oxides or materials with sulfhydryl functional groups. (e.g. NMSU, Weber State, Drexel University)

From Lab to Field: Sandia Pilot Test Program Summary

- **Pilot Test Demonstration Objectives**
  - Generate cost/performance data for innovative technologies for small communities
- **Technology Selection**
  - Initial technologies chosen from participants in Vendors Forum
  - Phase II test can involve experimental technologies from other Partners
- **Initial Pilot Studies**
  - Socorro, NM – February 2005 start
  - Desert Sands, NM – Fall 2005 start
  - Rio Rancho, NM – Fall 2005 start

Helping Communities

- Information gathered at Vendors Forum and Pilots available on Sandia Pilot project website:
  - http://www.sandia.gov/water/arsenic.htm
- WERC regional training courses
- WERC developed Comprehensive Arsenic Tool (CoAsT)
  - to be available at: http://www.arsenicpartners.org
    - Summaries of BATs
    - Several cost models
    - Decision tree
    - Beta-version of rate structure tool
- Sandia Rural Outreach Program
  - Outreach to individual communities in New Mexico

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AWTP Team Members

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Malynda Aragon, Alicia Aragon, Pat Brady, Sue Collins, Bryan Dwyer, Randy Everett, William Holub Jr., Richard Kottenstete, Jim Krumhansl, Justin Marbury, Tom Mayer, Jerome Wright, Emily Wright, Michelle Shedd, Carolyn Kirby, Hongting Zhao, Linnah Neidel, Nik Rael, Andres Sanchez, David Stromberg, Tom Hinkebein, John Merson

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Thank You

Questions?

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